THE EVALUATION OF THERMAL COMFORT INDICES IN HOUSEHOLDS

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Abstract - Interior buildings microclimate design is the result of a multicriteria optimization calculation that takes into account the thermal comfort and the energy savings. More complex problems appear in the existing buildingscase on to intervene through thermal rehabilitation,with aviero to assurance of an appropriate comfort level. This paper evaluates the level of thermal comfort in living rooms, with different structures of the envelope, orientation and location within a building condomeniale. Considering the results obtained in the evaluation of thermal comfort in rooms analyzed, it must determine the percentage of dissatis analyzed heat in all rooms. After performing the calculations, we obtained a value of the percentage of 7,142% dissatis heat, below the allowable minimum value of 10%. In this way, it results that for all the analysed rooms if the internal temperature is +20°C, all the thermal confort conditions are assured.

Keywords: buildings, thermal comfort, building envelope, energy savings, optimization.

1. INTRODUCTION

The reduction of the energy consumption in buildings represents one of the main research directions in building construction. A major part of the energy consumption of a household is related with the interior microclimate parameters.

Because most of the people tend to have 80…90% of their activities indoors, these spaces must satisfy:

- The possibility to undertake physical and intellectual activities;
- The possibility to undertake recreation activities in optimum conditions.

Designing closed spaces (such as buildings) represents a complex problem that might be solved by the simultaneous action of different technical, psihological and ergonomical factors.

Interior climate design for these buildings is the result of a multi-criterial optimisation calculation, tacking into account the thermal confort and the energy savings, with more complex problems for the rehabilitation of existing buildings.

Tacking into account that the notion of thermal confort consists of all the controled parameters that influence directkly the human well being and act dierctly over his senses. We might define the thermal confort notion as a subjective sensation that occurs within the human body due to a series of psihlogial and physical factors.

2. ASPECTS REGARDING THE THERMAL COMFORT AND THE INTERNAL MICROCLIMATE

The thermal comfort is determined on one side by a series of physical parameters (internal air temperature, average temperature of the enclosure surfaces, the relative humidity of the internal air and it's speed) and on the other hand by two parameters that related to the capacity of the human body to maintain the thermal equilibrium (heat production of the human body, the heat loss, the thermal – regulation the thermal resistance of the clothes and it's influence over the evaporation).

These last factors arte influenced by other basic factors: heat produced by the body respect to the age and the heat lost by the body respect to the clothes and the other factors mentioned before.

Starting from the thermal comfort factors, at one time the sensation of thermal comfort is defined by the comfort index *B* (relation 1), as being the conscious state that expresses happiness to the internal environment. The evaluation of this indicator consists of 7 stages: +3 (very hot); +2 (hot); +1 (mildly hot); 0 (neutral); -1 (slightly cold); -2 (cold); -3 (very cold).

$$B = C + 0{,}25 \cdot (t_i + \theta_{mr}) + 0{,}1 \cdot x - 0{,}1 \cdot (37{,}8 - t_i) \cdot \sqrt{v_i} \quad (1)$$

where,
C – constant with the value of –9,2 for the cold period and –10,6 in the hot period;
i_t – internal temperature, [°C];
θ_{mr} – average radiation temperature if the room, [°C];
x – internal humidity content, [gr/kg dry air];
v_i – internal air speed, [m/s].

The thermal confort calculation it's made acordingly to the PMV indexes (average rpedictive option for the thermal confort) and *PPD* (unsatisfactory predictive percentage. Acordingly to the *PMV* value +0,5 and –0,5 [4].

The thermal confort notion has a subjective character depinding by each individual behaviour. There is a corelation between the thermal confort and the microclimate parameters (the air temperature t_i, The

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average radiation temperature θ_{mr}, relative humidity φ_i, air speed motion v_i).

3. INTERIOR MICROCLIMATE PARAMETERS

a) Internal air temperature

In order to insure the thermal confort it is neccesary that the internal air temperature t_i will ensure an optimum average tempearture fro the inclosed walls for an optimum radiation heat exchange between the huuman body and the environmenrt.

The thermal confort criteria might be ilutsrated by a graphical relation (Fig. 1) between the the internal air, the outside temperature and the walls temperature thus resulting an average internal temperature btween 17 and 24°C in conformity with Romania's rules and regulations [4].

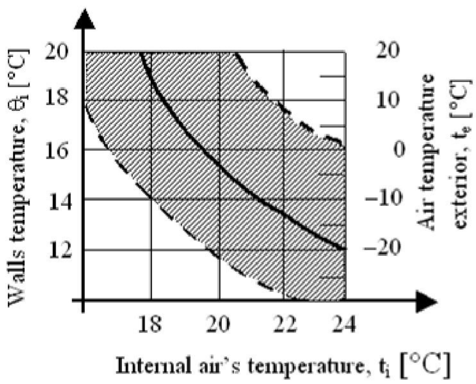

Fig. 1. Thermal confort respect to the internal tempearture, the external temperatureand the walls temperature

b) Average radiation temperature *(θ_{mr})*

This temperature represents an average temperature for the enclosure walls (walls, floors, ceilings, radiators, etc.), and the temperature felt by the inhabitants t_c might be also considered as an arithmetical average values of temperatures t_i and θ_{mr} [6].

From the confort diagram (Fig. 2) results that the internal temperature t_i might be chosen between 19 and 23°C, when the θ_{mr} temperature has equivalent values between 16 and 25°C, repecting the overlined area corelation: at the increase of t_i there is a decrease of θ_{mr}.

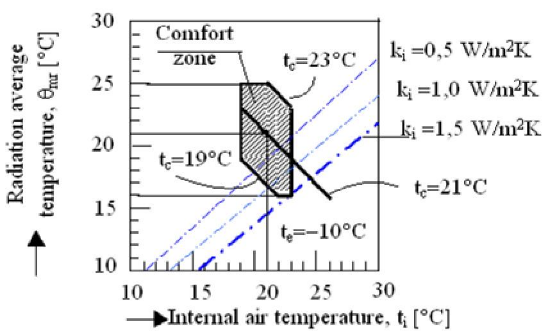

Fig. 2. Confort diagram respect to the internal air temperature, the average radiation temperature and the temoperature felt by the inhabitants

From a mathematical point of view the average radiation temperature represents the result of the radiation effect of the odies situated inside the the buildings, of the radiators and of the cold surfaces (relation 2).

$$\theta_{mr} = \frac{\sum S_j \cdot \theta_j}{\sum S_j} \qquad (2)$$

c) Relative humidity of the internal air

Water might intefere with the buyildings and the constrauction materials in several ways: by presure, capilary ascending, by the direct influence of the rain of the walls, the influence of construction procesus (concrete plaster, etc.). There might also other sources for the water produced inside a building: the buildings operation (bathrooms, kitchens, labs, etc), the water contained within the air, the condensation of the water vapors on the surface of the outside walls or by the respiration or the perspiration of the inhabitants.

As a result the humidity might be expressed by:

- the absolute humidity x_i of the water contained in an air volume for a given temperature and pressure. The absolute humidity is limited by a maximal value called *saturation humidity x_s*. It's value is influenced by the temperature inside a room (Fig. 3).

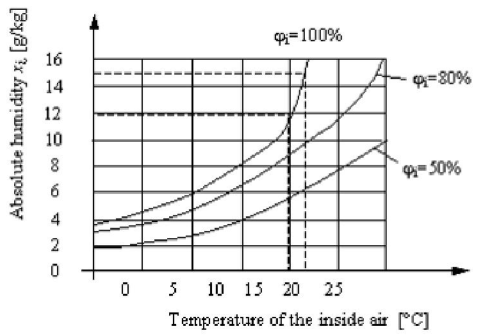

Fig. 3. Confort diagram absolute humidity – temperature of the insid air

- relative humidity of the inside air φ_i, reresents a ratio between the absolute humidity and the saturation one and has values between 50 and 90%, respect to the room's destination and their ventilation. The optimum values for the relative humidity in civil buildings are between 55…65%, depending on the temperature of the internal air 20…23°C (Fig. 4).

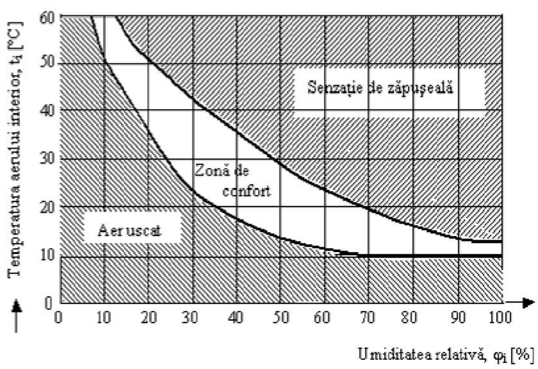

Fig. 4. Confort diagram for the internal air

d) Air speed

It is ecomended that the air motion speed should be smal enough. Usually the confort senasation it's negatively influenced if the air in motion has a smaller temeperature than the inside air and the flow is directed to body parts.

From the floor are and up to 2 m in height for rooms uin domestic house holds, with an internal temperature between 20…22°C, the admisibile air motion speed is beteen 0,1…0,15 m/s (Fig. 5).

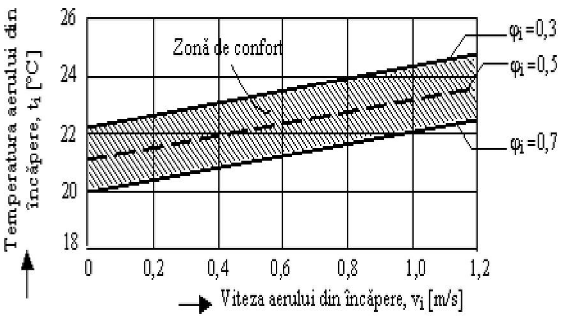

Fig. 5. Comfort diagram respect to the temperature and air motion speed

e) The activities and clothes

The International Standard Organisation (ISO) provided for the definition of thermal confort 6 main factors and an extra four indicators for the interior microclimate and he intensity of the work i_M, expresed in met[1] (human body heat radiation) and the thermal resistance of the clothes R_{cl}, expresed in clo[2].

The mechanisms that determines the thermal insulation produced by the clothes are very complicated and even often poorly understood. Usually the clothes must ensure the thermal equilibria.

Also the thermal comfort could be apreciated with a graphical interpretatin (Fig. 6), a diagram represented for $\varphi_i=50\%$ and that indicates the optimum felt temperature t_c respect to the clothes thermal resistance R_{cl} or R_h, with the labor intensity i_M and the methabolic energy *M*. The air motion speed must be considered $v_i=0$ for activities with $i_M \le 1$ met and $v_i=0,3$ for $i_M>1$.

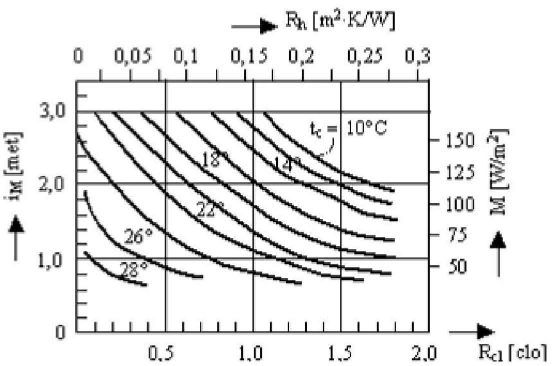

Fig. 6. The optimum temperaturemust be considered repect to the thermal resistance of the clothes, to the labour intensity and to the methabolic energy

[1] 1 met = 58 W/m²
[2] 1 clo = 0,155 m²K/W

4. THERMAL COMFORT LEVEL EVALUATION

The evaluation of teh termal confort level by a global indiocator or a general relation that takes into account all the factors was impossible to fiind since the present day, Fanger grouping the confort indices in the following way [5], [6]:

a) The evaluation indices of the thermal stress in extrem environmental conditions

This index allows the safety limits and limits of tolerance for high temperature environments. This cathegory includes: the PSr index (McArdl), the ITS stress index - Internationaly standardised by ISO-7243, the fisiological effect index (Robinson), Vogt and Metz diagrams etc.

b) Indices that include the effect of several parameters of environment:

b.1. The effective temperature, t_E, established by Yaglou, defined as the index that includes in the same value the temperature effect (measured with a dry thermometer), of humidity and air motion. This temperature produces the sensation of hot or cold as felt by the human body and might be calculated withh the relation (v_i<0,15 m/s):

$$t_E = 0{,}431 \cdot t_i + 0{,}408 \cdot \theta_{mr} - 0{,}141 \cdot \sqrt{v_i} \cdot (37{,}8 - t_i) + \\ + 0{,}182 \cdot \varphi_i \cdot p_s - 0{,}328 \qquad (3)$$

b.2. Resulting temperature t_R, established by Missenard, represents the uniform environment temperature with still air where the environmental temperqature is equal to the average radiation temperature that produces and equivalent sensation as the existing environment calculated with the relation:

$$t_R = \frac{\theta_{mr} + 3{,}17 \cdot t_i \cdot \sqrt{v_i}}{1 + 3{,}17 \cdot v_i} \qquad (4)$$

b.3. The equivalent temperature (t_{ech}=15...24°C), is defined as the air temperature in an enclosure where $v_i=0$ and $t_i=\theta_{mr}$ and where a black cylynder with the hight of 558 mm and the 190 mm diameter loses the same heat as in the environment in equivalent conditions, determined with:

$$t_{ech} = 0{,}522 \cdot t_i + 0{,}478 \cdot \theta_{mr} - 0{,}21(37{,}8 - t_i) \cdot \sqrt{v_i} \qquad (5)$$

3) PMV and PPD indices

These indices allow the assessment of thermal comfort, verification calculations are being made to asymmetric radiation. The use of the PMV it's recomended only when only for values between –2 and +2 the discomfort degree been evaluated by the PPD index:

$$PPD = PI = (34 - t_i) \cdot (v_i - 0{,}05)^b \cdot (a + c \cdot T_i) \qquad (6)$$

where,

t_u – humid thermometer temperature, [°C];

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t_g – neutral globe temperature [°C];
t_{as} – air temperature under solar radiation, [°C];
p_s – saturation pressure for the inside air, [bar];
PI – unsatisfactory percent, [%];
a, c – constants *(a=3,143* and *c=0,3696)*;
b=0,6223 – index;
T_i – turbulence coefficient .

5. EVALUATION OF THE CONFORT LEVEL IN A HOUSEHOLD

The case study presented in this paper presents an anlysis of the thermal confort conditions from a room of a condominium apartment P+4, with different orientations.

So we have considered the following room orientations:

- *type I* – groundfloor room with unheated basement, in the middle (Fig. 7);
- *type II* - groundfloor room with unheated basement, in the corner (Fig. 8);
- *type III* – room at an intermediary level placed in the middle (Fig. 7);
- *type IV* - room at an intermediary level placed in the corner (Fig. 8);
- *type V* – last floor room in the midle (Fig. 7);
- *type VI* – last floor room in the corner (Fig. 8).

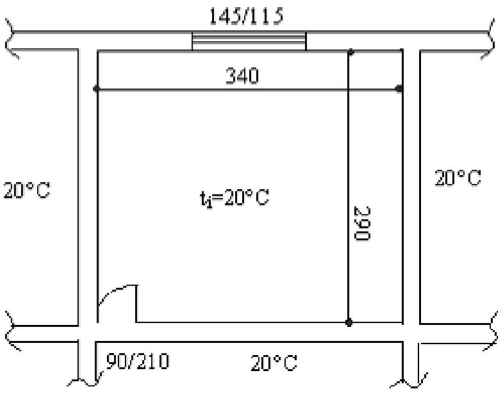

Fig. 7. Midle placed room dimensions (rooms type I, III, V)

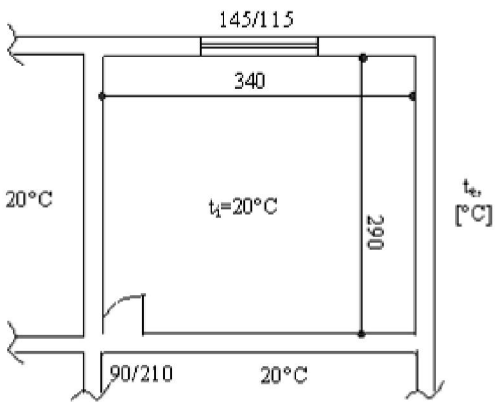

Fig. 8. Corner placed room dimensions (rooms type II, IV, VI)

The constructive structure is the following:

a) external walls (PE – Fig.9.a): cocrete plate with a width of δ_3=20cm with λ_3=1,62W/(m·°C), part of witch δ_4=4cm mineral wool with λ_4=0,045W/(m·°C), a layer of internal plaster with a width of δ_1=1,5cm with λ_1=0,70W/(m·°C) and an external plaster layer with width of δ_2=1,5cm with λ_2=0,93W/(m·°C);

b) interior wall (PI – Fig.9.b): autoclaved aerated concrete (BCA) with a width δ_5=12cm with λ_5=0,23W/(m·°C) and two layers of concrete with a width of δ_1=1,5cm each;

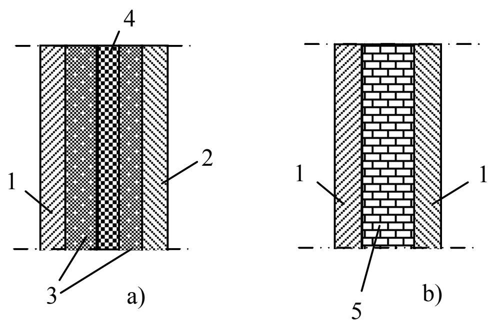

Fig. 9. Vertical perimeter elements constructive structure a) outside wall; b) inside wall

c) floors (Pd – Fig.10.a): internal plaster with a width of δ_1=1,5cm, concrete layer with a width of δ_3=20cm, equalisation layer with a width of δ_6=2cm with λ_6=0,75W/(m·°C), wood floor with a width of δ_7=0,4cm with λ_7=0,41W/(m·°C);

d) over the top floor terrace (Tv – Fig.10.b): interior plaster with a width of δ_1=1,5cm, concrete layer with a width of δ_4=20cm, equalisation layer with a width of δ_6=2cm, bitum hidroinsulation with a width of δ_8=0,1cm with λ_8=0,17W/(m·°C) and a layer of small rocks with width of δ_9=4cm with λ_9=0,93W/(m·°C);

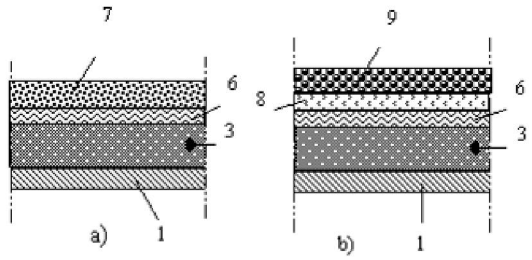

Fig. 10. Constructive structure of the horizontal perimeter elements: a) floor and ceilings for the intermediary levels; b) floor decking over

e) external windows (FE): coupled, with window glass at distance of 2...4cm, with a wooden frame with R=0,39(m^2·K)/W;

f) external doors (UI): from glued cardboard with a width of δ_{10}=4cm with λ_{10}=0,17W/(m·°C).

The analysis starts from the necesary heat evaluation for the six room types with different geographical orientations (N, S, E, V) and for different values for the outside temperature (t_e= +10°C; +5°C; 0°C; -5°C; -10°C; -15°C), also checking the thermal confort conditions. We consider that rooms are part of a building with double expousure from the second climatic area and the third wind area ($v^{4/3}$=7,45$(m/s)^{4/3}$), with a season duration of 180 days/year.

The heating system uses clasic cast iron radiators, in centralised regime with hot water 85°/65°C, with a surface of S=4,32m^2.

For the determination of average temperature radiation we have considered the thermal resistance of the construction elements 0,125 m^2K/W for walls and ceilings and 0,172 m^2K/W for floors.

For the determination of the confort index B we have used the relation 1 imposing the following parameters: absolute humidity of the air x=7 gr/kg, air currents speed v_i=0,1 m/s, neighbouring internal spaces temnperature t_u=+10°C, air relative humidity φ_i=50%, air saturation pressure p_s=0,02 bar and the turbulence coefuicient T_i=40%.

The results obtained by the calculations, by the use of standards and methods [7], [8], are presented in a centralised maner in tables 1 and 2.

Table 1. Heat necessary and the confort degree for I, III and V rooms

Outside temperature t_e, [°C]	Δt [°C]	Q_{inc}, [kcal/h] Geographical Orientation			Duration of annual heating, τ, [h/an]	$Q_{inc,an}$, [Gcal/an] Geographical Orientation			θ_{mr} [°C]	t_E [°C]	B	Obs.
		N	E,V	S		N	E,V	S				
I. Room type I												
+10	10	402,8	387,3	371,8	4320	1,74	1,67	1,61	23,44	17,86	+1,79	Mildly hot to hot
+5	15	604,2	581,0	557,8		2,61	2,51	2,41	23,25	17,00	+1,75	
0	20	805,6	774,7	743,7		3,48	3,35	3,21	23,12	16,93	+1,72	
-5	25	1007,1	968,3	929,6		4,35	4,18	4,02	22,99	16,88	+1,69	
-10	30	1208,5	1162,0	1115,5		5,22	5,02	4,82	22,87	16,83	+1,65	
-15	35	1409,9	1355,6	1301,4		6,09	5,86	5,62	22,74	16,78	+1,62	
III. Room type III												
+10	10	172,6	167,0	161,4	4320	0,75	0,72	0,70	24,09	17,33	+1,96	Mildly hot to hot
+5	15	258,9	250,5	242,2		1,12	1,08	1,05	23,90	17,25	+1,91	
0	20	345,2	334,0	322,9		1,49	1,44	1,39	23,77	17,20	+1,88	
-5	25	431,5	417,5	403,6		1,86	1,80	1,74	23,64	17,15	+1,85	
-10	30	517,8	501,1	484,3		2,24	2,16	2,09	23,51	17,09	+1,82	
-15	35	604,1	584,6	565,0		2,61	2,53	2,44	23,39	17,04	+1,78	
V. Room type V												
+10	10	474,0	455,6	437,2	4320	2,05	1,97	1,89	23,41	17,05	+1,79	Mildly hot to hot
+5	15	711,0	683,4	655,8		3,07	2,95	2,83	22,97	16,87	+1,68	
0	20	948,0	911,2	874,4		4,10	3,94	3,78	22,53	16,69	+1,57	
-5	25	1184,9	1139,0	1093,0		5,12	4,92	4,72	22,10	16,52	+1,46	Mildly hot
-10	30	1421,9	1366,8	1311,6		6,14	5,90	5,67	21,66	16,34	+1,35	
-15	35	1658,9	1594,5	1530,2		7,17	6,89	6,61	21,23	16,16	+1,24	

Table 2. Heat necessary and the confort degree for II, IV and VI rooms

Outside temperature t_e, [°C]	Δt [°C]	Q_{inc}, [Gcal/h] Geographical Orientation		Duration of annual heating, τ, [h/an]	$Q_{inc,an}$, [Gcal/an] Geographical Orientation		θ_{mr} [°C]	t_E [°C]	B	Obs.
		V, N	E, S		V, N	E, S				
II. Room type II										
+10	10	490,4	471,4	4320	2,12	2,04	23,27	17,00	+1,76	Mildly hot to hot
+5	15	735,7	707,0		3,18	3,05	23,00	16,88	+1,69	
0	20	980,9	942,7		4,24	4,07	22,79	16,80	+1,63	
-5	25	1226,1	1178,4		5,30	5,09	22,57	16,71	+1,58	
-10	30	1471,3	1414,1		6,36	6,11	22,36	16,62	+1,53	
-15	35	1716,5	1649,8		7,42	7,13	22,15	16,54	+1,47	Mildly hot
IV. Room type IV										
+10	10	254,3	245,2	4320	1,10	1,06	23,92	17,26	+1,92	Mildly hot to hot
+5	15	381,5	367,7		1,65	1,59	23,64	17,15	+1,85	
0	20	508,6	490,3		2,20	2,12	23,43	17,06	+1,79	
-5	25	635,8	612,9		2,75	2,65	23,22	16,97	+1,74	
-10	30	762,9	735,4		3,30	3,18	23,01	16,89	+1,69	
-15	35	890,1	858,1		3,85	3,71	22,80	16,80	+1,64	
VI. Room type VI										
+10	10	561,1	539,2	4320	2,42	2,33	23,24	16,98	+1,75	Mildly hot to hot
+5	15	871,7	808,8		3,64	3,49	22,72	16,77	+1,62	
0	20	1122,3	1078,3		4,85	4,66	22,20	16,56	+1,49	Mildly hot
-5	25	1402,9	1347,9		6,06	5,82	21,68	16,34	+1,36	
-10	30	1683,4	1617,5		7,27	6,99	21,16	16,13	+1,23	
-15	35	1964,0	1887,1		8,48	8,15	20,64	15,92	+1,10	

6. FINAL RESULTS AND GENERAL CONCLUSIONS

Regarding the annual value of the necessary heat we might see that it varies respect to the outside temperature and the rooms orientation (Fig. 11...16).

So it is possible to observe that in order to ensure the confort conditions the necessary heat varies between 1,39 Gcal/year for a type III room at an outside temperature of 0°C, to 4,85 Gcal/year , For a type IV room at the same outside temperature of 0°C.

Tacking into account the resiults obtained for the thermal confort evaluation it is of outmost inmportance the determination of the number of unsatisfied inhabitants by the use of the relatiion 7 considering a turbulence factor of 40 % for allt the rooms. After these calculation the cota of the unsatisfied inhabitants is 7,142%, below the admisibile value of 10%. In this way it results that for all the analysed rooms if the internal

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temperature is +20°C all the thermal confort conditions are fulfiled.

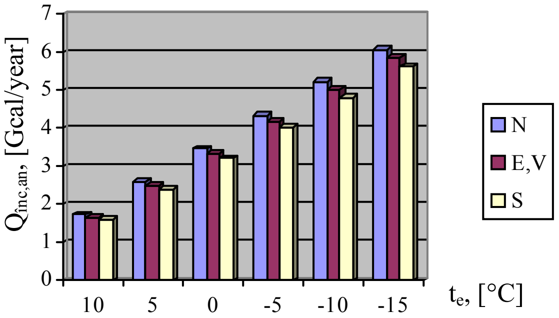


Fig. 11. Annual variation of heat necessary for heating depending on outside temperature and geographical guidelines for indoor type I facades

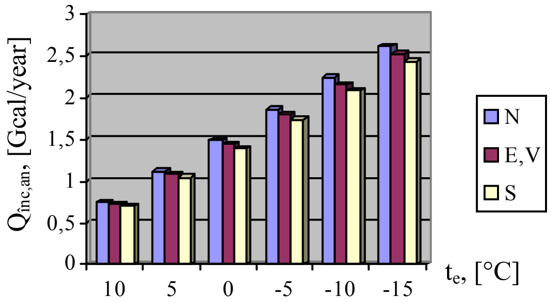


Fig. 12. Annual variation of heat necessary for heating depending on outside temperature and geographical guidelines for indoor type III facades

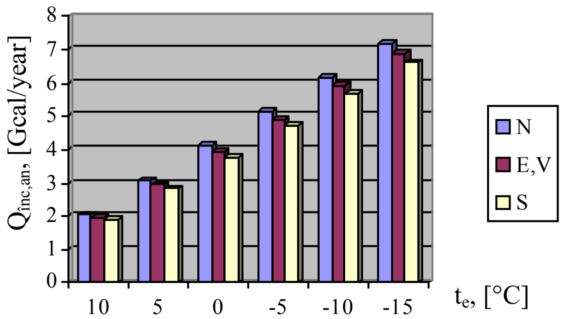
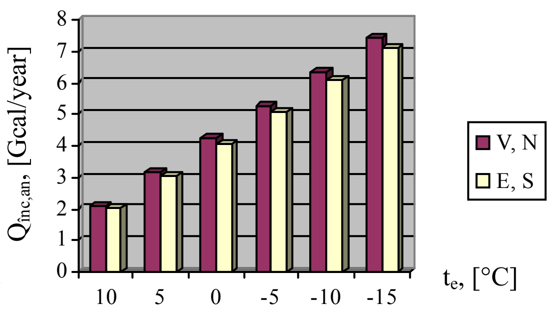


Figure 13. Annual variation of heat necessary for heating depending on outside temperature and geographical guidelines for indoor type V facades



[9].

Fig. 14. Variation of heat necessary for heating temperature according to room type II

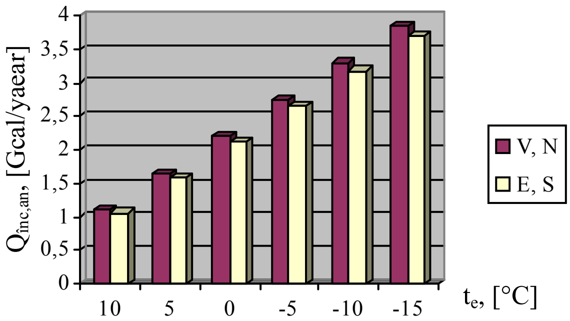


Fig. 15. Variation of heat necessary for heating temperature according to room type IV

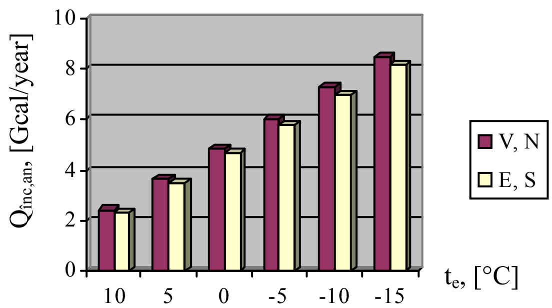


Fig. 16. Variation of heat necessary for heating temperature according to room type VI

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